7. TROPICAL CYCLONE SUPPORT SUMMARY

7.1 SCATTEROMETER APPLICATIONS FOR TROPICAL CYCLONES

J.D. Hawkins
Naval Research Laboratory
Monterey, CA 93943

R.T. Edson
Joint Typhoon Warning Center,Guam

P.S. Chang
NOAA/NESDIS
Camp Springs, MD 20746

Surface wind vectors from the scatterometer aboard the European Remote Sensing Satellite (ERS-1) are playing an increasingly important role to the JTWC. These remotely sensed wind vectors serve to fill a data void at the surface over much of JTWC's area of responsibility (AOR). In addition, as these data became more readily available in near real time during 1995, they increasingly served to supplement the existing reconnaissance platforms with tropical cyclone (TC) vortex locations and the depiction of gale force winds (35 kt (17m/sec)). As the year went on, much of this information became available in time to support the current JTWC warning.

The scatterometer houses an active radar and it records the change in radar reflectivity of the sea due to the perturbation of small ripples (capillary waves) by the wind close to the surface. The radar backscatter returned to the satellite is modified by wind-driven ripples on the ocean surface and, since the energy in these ripples increases with wind velocity, backscatter increases with wind velocity. Wind vector data have shown to be extremely reliable between the range of 3-50 kt (1-25 m/sec) with a root-mean-square (rms) error of 1-2m/sec and a wind directional accuracy of 15-20 degrees rms.

Horizontal data resolution is depicted at up to 25km. Although the sensor is subject to a 180 degree directional bias, the trained analyst can readily identify the true direction of the wind vector. As an active radar, the scatterometer is less sensitive to rain attenuation as compared to passive microwave sensors such as the SSM/I . The primary handicap of the scatterometer remains its fairly narrow, 500 km, swath-width as it flies aboard the sun synchronous ERS satellite.

Prior to the 1995 season, use of scatterometer data was a hit or miss proposition. In addition to its narrow swath, data, when available, was generally received anywhere from 8-24 hours after data time. During 1995, arrangements were made through NOAA/NESDIS and NRL-Monterey to receive the data in a more systematic, quicker manner. After NOAA/NESDIS received the data from the European Space Agency (ESA), the data were quickly remapped into specifically requested boxes covering the JTWC AOR. The images were transferred in Tagged Image File Format (TIFF) via File Transfer Protocol (FTP) to JTWC and NRL, usually within 3 to 8 hours of data time. By late 1995, these images became available even quicker via the Internet/World Wide Web. A large scale depiction of the entire globe became available with all current swaths. The user may now further request a 25km resolution blow up over an area of interest. Data over the entire globe are now available within 2 to 4 hours of fly-over. Additionally, toward the end of 1995, the Naval Oceanographic Office (NAVO-CEANO) also came on line with a global scatterometer view of the ERS data set, available on the Internet, giving the JTWC a second source to access this valuable data.

Scatterometer wind vectors played a crucial role in depicting "closed circulations" and enabling the TDO to more accurately analyze

both the location and the organization of a developing TC. This information proved to be especially important for those systems that had yet to show a good cloud signature in either the infrared or visual imagery and were used several times in 1995 to relocate poorly defined systems. Once developed, the wind swaths were regularly used to depict both the size and asymmetrical character of the 35 kt (17 m/sec) wind radii. Scatterometer winds are now also routinely incorporated into the TDO's overall synoptic analysis by attaching the individual wind swaths to the daily gradient-level wind chart. This has proved invaluable in filling large data gaps and in aiding the TDO in interpreting the often complex wind flow over the AOR.

Future efforts will focus on the inclusion of two new scatterometer platforms. Full use of the new ERS-2 will begin in the spring of 1996 and will eventually replace the ERS-1 scatterometer. In addition, the NASA Scatterometer (NSCAT) is expected to be launched on the Japanese Advanced Earth Observing Satellite (ADEOS) in August 1996 and has more than twice the swath width (1200km) of the current ERS instruments.

7.2 WATER VAPOR TRACKED WINDS FOR TROPICAL CYCLONE APPLICATIONS

J.D. Hawkins
Naval Research Laboratory
Monterey, CA 93943

T.L. Olander
S.T. Wanzong
C.S. Velden
Cooperative Institute for Meteorological
Satellite Studies, University of Wisconsin
Madison, Wisconsin

R.T. Edson
Joint Typhoon Warning Center, Guam

Upper-level wind vectors over the western North Pacific and eastern Indian Ocean are now routinely being derived from GMS-5 water vapor imagery. Water vapor tracked winds, using a set of three half-hourly water vapor images, are created at 00Z and 12Z to map the upper-level wind field from 150-500 mb. These wind vectors, superimposed on a GMS-5 water vapor image, are color coded to represent wind data within three layers of the upper atmosphere: 150-250 mb, 250-350 mb and 350-500mb. These data are an excellent supplement to the more traditional cloud track winds due to the fact that they do not require clouds to be present.

Areas in the tropics with high moisture levels (e.g., areas near active intense convection) typically produce wind vectors at levels from 150-250 mb while drier, cooler regions permit retrievals closer to levels between 350-500 mb. This vertical distribution of water vapor tracked winds (WVTW) has provided a wealth of information of the large scale three-dimensional flow within the Joint Typhoon Warning Center's (JTWC) area of responsibility (AOR). The transmitted images are now routinely attached to the back of the 200-mb (upper-level) wind analysis charts in order to supplement the existing data. This has proven crucial in defining the synoptic patterns of ridges, troughs, TUTTS, cut-off lows, etc., that can be difficult to map in the relatively data void oceanic regions of the western Pacific and Indian Oceans. In addition, the added data have been used qualitatively to determine individual tropical cyclone track and intensity tendencies. Initial results during the fall of 1995 with Typhoons Ward and Angela were very promising.

The GMS-5 data are accessed via Australia and transferred via File Transfer Protocol (FTP) to the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin. These data are then processed to create the wind data sets and the final product is transferred in Tagged Image File Format (TIFF)

via FTP to JTWC and Naval Research Laboratory, Monterey (NRL-MRY) within two hours of the image time. Reliable FTP capabilities at all sites has been the largest obstacle to date.

Considerable attention has been given to the quality of the retrievals. Upper-level wind data from radiosonde island and mainland stations have been collocated with the WVTWs to produce statistical comparisons. Over 15,000 RAOBS have now been matched in time and space with WVTWs and indicate the root mean square error (RMSE) is ~ 7 m/sec (14 kts). This is comparable to the values for cloud tracked winds.

Quality control includes extensive buddy checks with neighboring observations and comparisons with a first guess field, and ensures that vertical consistency is maintained. Results over the last 6 months have shown that very few poor vectors have been produced. Tests continue, refining height assignments which now have an error near 50 mb.

Demonstrations in early 1996 indicated that WVTW retrievals in the Southern Hemisphere are feasible. NRL-MRY and CIMSS are planning to produce data in this area for the next season.

7.3 SSM/I DERIVED STRUCTURE AND INTENSITIES FOR TROPICAL CYCLONES

J.D. Hawkins
Naval Research Laboratory
Monterey, CA 93943

J.C. Sandidge
R.J. Holyer and D. May
Naval Research Laboratory
Stennis Space Center, MS 39529

M. Helveston
Analysis & Technology
Bay St. Louis, MS 39520

Passive microwave digital data from the DMSP Special Sensor Microwave/Imager (SSM/I) is being studied to extract information on the structure and intensity of tropical cyclones. SSM/I data can penetrate many of the higher cloud decks that hinder the analyst's ability to see the low-mid level cloud organization that is crucial in determining tropical cyclone (TC) structure and intensity. The SSM/I's capability to depict the rainbands, eyewall, eye and other pertinent features is being studied and compared with visible and infrared imagery, best track data, and aircraft reconnaissance data.

Over 350 SSM/I passes over TCs ranging in intensity from tropical depressions to super typhoons have been processed. Data have been collected from all major basins, with the main emphasis on the western Pacific (to support the Joint Typhoon Warning Center, JTWC) and the Atlantic basin (to compare with aircraft radar and intensity estimates). This joint Naval Research Laboratory (NRL) effort has taken advantage of the real time global receiving abilities at Stennis Space Center and the full digital archive at NRL-DC (Washington D.C.). In addition, we are coordinating with the Hurricane Research Division, Miami in order to compare P-3 Orion aircraft Doppler radar data with the SSM/I data set.

Initial efforts were directed at qualitatively comparing SSM/I 85-GHz imagery to coincident infrared (IR) data from the Operational Linescan System (OLS). The advantages the passive microwave data has in seeing through much of the upper level cirrus clouds was readily noticed. TC structure in the 85-GHz imagery was clearly evident despite the upper-level cloudiness and the 12-15 km resolution of the microwave data. An analysis of the 85-GHz data for a given TC's evolution readily depicted structural changes in the rainbands, eyewall and eye, including eyewall cycles (Willoughby). Early results show a surprising increase in frequency of eyewall cycles as seen in the microwave data as compared to the previously

used aircraft radar data.

Next, a more quantitative Neural Network (NN) approach was begun by looking at intensity changes from 85 GHz TC structure characteristics. The NN approach was initially selected by using approximately 130 85-GHz images to develop the NN and 30 cases to test the accuracy. This was done by using Empirical Orthogonal Functions (EOFs) to represent the structure in the 85-GHz image data set, extracting the top five coefficients (explaining > 40% of the variance) and inputting this information into the NN along with the best track intensities.

Initial results as compared to official best track data were poor. Next, a training set using "past" intensity values in the form of either 12 or 6 hour old best track intensities was included into the NN along with the 5 EOF coefficients. These results showed an improvement slightly better than persistence. An effort is now underway to eliminate the best track data and to produce a new NN intensity estimate earlier in the life of a TC (e.g. as a tropical depression) and then use this value as input to the NN along with the 5 coefficients. This may permit the NN to "learn" as the storm progresses. In addition, the data set has been expanded by a factor of two (~350) and is continually being upgraded. Particular emphasis is now being placed on processing SSM/I data coincident with 1995 Atlantic storms that have extensive aircraft reconnaissance fixes.

The NN results suggest that valuable information is contained in the SSM/I data and improvements over persistence are obtainable.

7.4 JTWC'S 120-HOUR OUTLOOK

E. J. Trehubenko
Joint Typhoon Warning Center, Guam

JTWC now provides a 120-hour "outlook" on tropical cyclone position and intensity — 48 hours beyond the 72-hour period covered by JTWC's Tropical Cyclone Warnings. The 96- and 120-hour outlooks are realized through the Horizontal Weather Depiction (HWD) products produced by the Operations Department of the NPMOCW, Guam. The TDO provides specific input to the Forecast Supervisor at NPMOCW regarding the development potential of existing tropical disturbances, as well as position and intensity estimates through 120 hours. For tropical cyclones in a warning status, 96- and 120-hour position and intensity estimates are provided, along with the latest 72-hour warning for the respective system. Within the JTWC, the 120-hour outlook is entered as an objective aid, the J120. Tools available to the TDO to support the J120 include NOGAPS (NGPX), the Bracknell Model (EGRR), and the new R120 objective aid. The J120 sample size for 1995 was small (50) but results from the initial test year show promise when compared to guidance provided by the dynamic models and climatology.

7.5 THE R120 OBJECTIVE AID

J.A. Rupp
Joint Typhoon Warning Center, Guam

The R120 objective forecast aid was created to address the absence of climatological guidance in the extended forecast period past 72 hours. The R120 aid was created by Capt John Rupp, USAF. This new objective aid was tested during the 1995 in the western North Pacific. The R120 is a Cliper model that uses the 48 and 72 hour forecast points from the JTWC forecast to project a Cliper forecast to the 96 and 120 hour. It was designed to answer the question of where would climatology take the system if it were to follow the first 72 hours of the forecast track (the currently available clipper model only runs out to 72 hours). The advantage of adding the Cliper guidance to the end of the JTWC warning is that it can benefit from the proven skill at 72 hours and hence outperform a Cliper model initialized from only initial conditions.

The results from the initial test year show promise in having competitive skill with other dynamic aids.

7.6 MONSOONAL INFLUENCES ON TROPICAL CYCLONE MOTION AND STRUCTURE

M.A. Lander
ONR-sponsored research at the
University of Guam
Mangilao, Guam

The low-level summer monsoon circulation of the tropical western North Pacific can appear in the form of a trough or a large gyre. These two broad categories of the monsoon circulation have important implications for the site of genesis, size, and subsequent motion of TCs which form in them.

Lander (1995) focused upon the flow pattern of a monsoon gyre which formed during August 1991. This monsoon gyre had a long (20-day) life and was associated with the genesis of six TCs. The August 1991 monsoon gyre was representative of a distinct pattern type of the monsoon circulation of the WNP which repeats roughly once every other typhoon season at some time during July through mid-October. A monsoon gyre is associated with TCs of extremely small and extremely large size. Only a few studies have been written which have focused on TC size (e.g., Arakawa 1952; Brand 1972; and Merrill 1984). Further understanding of the mechanisms governing TC size may well arise from a close study of the monsoon gyre.

Lander (1996) describes the reverse-oriented monsoon trough and its association with north-oriented TC motion. In its simplest description, the large-scale low-level circulation of summer over the WNP can be described in terms of low-latitude southwesterlies, a monsoon trough and a subtropical ridge. The axis of the summer monsoon trough of the WNP usual-

ly emerges from East Asia at about 20° N to 25°N, and extends southeastward to a terminus southeast of Guam (13° ; 145°E). Most of the TCs which develop in the WNP form in the monsoon trough. When the axis of the monsoon trough is in its normal orientation (NW-SE), TCs tend to move northwestward on tracks close to those expected from climatology. As an episodic event, the axis of the monsoon trough becomes displaced to the north of its usual location and takes on a reverse (SW-NE) orientation. When the monsoon trough acquires a reverse orientation, TCs within it tend to exhibit unusual motion, including: northeastward motion at low latitude; long meandering northward tracks; and binary interactions with other TCs along the trough axis. A TC track type, defined as the "S" track, appears to be primarily associated with reverse-orientation of the monsoon trough.

7.7 A TECHNIQUE FOR ESTIMATING RECURRENCE INTERVALS OF TROPICAL CYCLONE RELATED HIGH WINDS IN THE TROPICS: RESULTS FOR GUAM

J.A. Rupp
Joint Typhoon Warning Center
and
M.A. Lander
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

Rupp and Lander (1996) developed a technique that applies existing analytical models of the radial profile of the wind in tropical cyclones to the historical best-track data-base of tropical cyclones in a particular region in order to estimate the wind (at one-hour intervals) experienced at any selected location in the region for any or all of the historical tropical cyclones. Focusing on Guam, we produced a time series of the maximum wind there for each

tropical cyclone in the Guam region during the period 1945 to 1993. The purpose of the technique was to produce a time series of tropical-cyclone related winds that could be used to compute recurrence intervals for extreme wind speeds at any selected tropical location. We condensed the original time series of the estimated wind speeds (at one-hour time steps) for each historical tropical cyclone to a time series of the highest annual tropical-cyclone related wind. Extreme value analysis was applied to the time series of annual peak wind to estimate the recurrence intervals for threshold values of extreme wind speeds. The island of Guam was selected as the site for testing the technique. Guam has excellent historical measurements of wind, from which an independent estimate of the recurrence intervals of selected threshold high wind speeds can be computed. In addition, the wind traces during the passage of several major typhoons which affected Guam were used to assess the ability of the technique to reproduce the wind trace (at hourly intervals) experienced there during the passage of these typhoons. The recurrence intervals computed from our technique match the recurrence intervals computed from the wind measurements. The technique also reproduces a reasonable wind trace for the major typhoons affecting Guam. We believe that our technique can be used to make useful estimates of the recurrence intervals for tropical cyclone related high wind speeds at any tropical location where an historical best-track archive of tropical cyclones exists.

7.8 A SAFFIR-SIMPSON-LIKE HURRICANE DAMAGE POTENTIAL SCALE FOR THE TROPICAL WESTERN PACIFIC OCEAN REGION

C.P. Guard and M.A. Lander
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

The Saffir-Simpson Hurricane Scale (Simpson 1974) commonly used in the Atlantic to relate potential damage to maximum wind speed, has been adapted for use in the tropical western Pacific (hereafter, the Tropical Saffir-Simpson Tropical Cyclone (TSS TC Scale). The TSS TC Scale employs the basic model of the Saffir-Simpson Hurricane Scale which has been used for many years along the Atlantic and Gulf of Mexico coastal areas of the United States. After five years of modification and testing, the TSS TC Scale has been fine-tuned and implemented for use in the western North Pacific. The TSS TC Scale incorporates the basic Saffir-Simpson Scale, but modifies it for tropical building materials and building practices; considers the detrimental effects of termites, wood rot, and airborne sea salt; and it relates the wind speed to specific levels of damage to tropical vegetation and agriculture. Special consideration is given to the oceanic inundation that can be expected from tropical cyclone-related high surf and elevated tidal levels on the various structures (e.g., fringing coral reefs) common to the coasts of tropical Pacific Islands. Because many of the islands of the tropical Pacific contain crops and shelters that are highly susceptible to damage by sub-hurricane-force winds, the TSS TC Scale addresses the potential damage from the winds and seas associated with tropical depressions and tropical storms as well as with typhoons. With minor changes, the TSS TC Scale should be applicable in the global tropics.

270

7.9 DEVELOPMENT OF A HIGH-CONFIDENCE TROPICAL CYCLONE INTENSITY DATA BASE

C.P. Guard and M.A. Lander
ONR-sponsored research at the
University of Guam
Mangilao, Guam

A close investigation of the tropical cyclone intensity data bases of JTWC and of other warning centers around the world reveals that the quality of the data bases may not be sufficient for tropical cyclone intensity studies and validation of remote-sensing algorithms. Work on a "high-confidence" intensity data base, that reevaluates the raw data, makes changes to intensity data bases (where they are warranted), then places a confidence level on the intensity depending on the quality of the raw data on which the near-surface intensity was based, is continuing. Weighting values are developed for the confidence levels. An important input to the reevaluation is the maximum intensity (e.g., peak gusts and minimum sea-level pressure) measured near the centers of landfalling tropical cyclones. These data are not routinely available to warning centers outside the country of occurrence. In conjunction with this initiative is the acquisition from as many countries as possible (e.g., Taiwan, Japan, Philippines, Hong Kong, Australia, India) of maximum intensity data for landfalling tropical cyclones.

7.10 AN INITIAL LOOK AT WIND DISTRIBUTION FORECAST CAPABILITIES AT THE JOINT TYPHOON WARNING CENTER

C.P. Guard and M.A. Lander
ONR-sponsored research at the
University of Guam
Mangilao, Guam

A study was conducted to ascertain JTWC's ability to predict the gale (>34 kt) and storm force (>48 kt) wind distribution (WD). A primary stratification was made where each tropical cyclone was divided into its strong sector (i.e., right semicircle with respect to the translation in the Northern Hemisphere) and weak sector (i.e., the left side). Forecasts were compared to the appropriate analyses, where data were sufficient to identify the radial extent of gales and storm-force winds in the strong and weak sectors. Of 26 selected tropical cyclones with a total of 586 warnings, there were 122 strong sector gale WD verifications, 73 gale WD weak sector verifications, 38 strong sector storm-force WD verifications, and 29 weak sector storm-force WD verifications. Characteristics of the data availability, absolute errors, and error biases were presented by the author at the 1996 MGPACOM Typhoon Conference and at the 50th Interdepartmental Hurricane Conference. An example of the bias was an under-forecast of the strong sector gale and storm-Force WD, and an over-forecast of the weak sector gale and storm-force WD.

7.11 THE NATURAL VARIATION IN THE RELATIONSHIP BETWEEN THE MAXIMUM WIND AND MINIMUM CENTRAL PRESSURE IN TROPICAL CYCLONES

M.A. Lander and C.P. Guard
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

A four-year investigation of the relationships between the maximum wind and the minimum sea-level pressure in tropical cyclones is nearing completion. The study reveals the physical parameters that contribute to the wind-pressure relationships (WPR), and weights the importance of the various parameters. The radius of maximum wind (RMW) (closely related to eye size) and the rate of "fall-off" of the winds between the RMW and the environmental

flow (closely related to the size of the tropical cyclone) are found to be the most important parameters. The natural variability between observed maximum wind speed and minimum sea-level pressure is explained in terms of the identified parameters. A set of universal, basin-independent WPRs is proposed.

7.12 A STUDY OF THE CHARACTERISTICS OF VERY SMALL (MIDGET) TROPICAL CYCLONES

C.P. Guard and M.A. Lander
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

A special case of the study of the relationship between the maximum wind and minimum central pressure in tropical cyclones addresses the "midget" or very small tropical cyclone (TC) in which the minimum sea-level pressure is observed to be 20 mb higher for a specific maximum sustained wind speed than is the case for large TCs. The study identifies the unique characteristics of these cyclones and presents some proposed mechanisms for their development and commencement of rapid intensification at lower-than-normal threshold intensities. A basin-independent wind-pressure relationship is derived for midget TCs.

7.13 A STUDY OF RAPID INTENSITY FLUCTUATIONS OF TROPICAL CYCLONES USING THE DIGITAL DVORAK ALGORITHM

M.A. Lander
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

One of the utilities installed in the JTWC's MIDDAS satellite image processing equipment is an automated routine for computing Dvorak "T" numbers for tropical cyclones that possess eyes. The routine, developed by Zehr (personal communication), adapts the rules of the Dvorak technique as subjectively applied to enhanced infrared imagery (Dvorak 1984) in order to arrive at an objective T number, or "digital Dvorak" T number (hereafter referred to as DD numbers). Infrared imagery is available hourly from the GMS satellite, and hourly DD numbers were calculated for several of the typhoons of 1995.

The DD numbers presented are experimental, and methods for incorporating them into operational practice are being explored. In some cases, the DD numbers differ substantially from the warning intensity and also from the subjectively determined T numbers obtained from application of Dvorak's technique. The output of the DD algorithm, when performed hourly, often undergoes rapid and large fluctuations. The fluctuations of the DD numbers may lay the ground work for future modifications to the current methods of estimating tropical-cyclone intensity from satellite imagery. The discussion of the behavior of the time series of the DD numbers for some of the typhoons of 1995 (e.g., see the summaries of Oscar (17W), Polly (18W), Ryan (19W), Ward (26W), and Angela (29W)), is intended to highlight certain aspects of the DD time series that may prove to have important research and/or warning implications.

If the DD numbers truly represented rapid (on the order of 3 to 6 hours) intensity fluctuations with magnitudes (30-40 kt) as large as seen with some typhoons, there are two topics for further research: (1) how are the extremely rapid fluctuations of intensity, if they are genuine, to be incorporated into the warning? and, (2) how can the best tracks, having had these rapid fluctuations removed, be used to study the processes governing what may prove to be real intensity fluctuations of the magnitude indicated by the DD numbers?

7.14 ON THE INTERANNUAL VARIATIONS IN GLOBAL TROPICAL CYCLONE ACTIVITY

M.A. Lander and C.P. Guard
ONR-sponsored typhoon research at the
University of Guam
Mangilao, Guam

During 1995, there was a well-publicized near-record tropical cyclone (TC) activity in the Atlantic. This activity fueled speculation that it marked a tangible signal of global climate change. Although the Atlantic was very active during 1995, activity in other worldwide basins was generally below normal. An ongoing study of the global TC distribution by the authors has led to the following preliminary conclusions:

(1) The global annual average number of TCs is 88/year, ranging from the low 70s to the low 100s.

(2) There are global "jackpot" years (> 100 TCs) and "meager" years (< 80 TCs); the TC activity in each ocean basin also features "jackpot" years and "meager" years (Table 7-1).

(3) There is an ENSO connection to the global number of TCs — the global average is low during both the warm (i.e., El Niño) years and the cold (i.e., La Niña) years.

(4) Global "jackpot" years occur during normal (i.e., non-El Niño, non-La Niña) years.

(5) There are some weak, but statistically significant positive correlations between the annual number of TCs in the western North Pacific and the annual number of TCs in the eastern North Pacific, and between the annual numbers of TCs in the Southern Hemisphere and the annual numbers of TCs in the Western North Pacific. There were no statistically significant correlations found to exist between the Atlantic basin and any other TC basin.

Table 7-1	TROPICAL CYCLONE DISTRIBUTION		
Basin	1995	long-term average	"jackpot" years
WNP	26	28	1994
SH	22	28	1986, 1992
ENP	10	17	1992
NIO	4	5	1992
NAT	19	10	1995

BIBLIOGRAPHY

Arakawa, H., 1952: Mame Taifu or midget typhoon (small storms of typhoon intensity). *Geophysical Magazine*, 24, pp 463-474.

Atkinson, G.D., 1974: Investigation of gust factors in tropical cyclones. FLEWEACEN Tech. Note: JTWC 74-1. Photocopy available from: JTWC, COMNAVMAR, PSC 489, Box 17, FPO AP 96536-0051.

Atkinson, G. D. and C. R. Holliday, 1977: Tropical cyclone minimum sea-level pressure and maximum sustained wind relationship for the western North Pacific. *Mon. Wea. Rev.*, 105, No. 4, pp 421-427 (also Fleet Weather Central/JTWC Technical Note 75-1).

Australian Bureau of Meteorology, 1995: Monthly 850-mb wind anomalies. Darwin Tropical Diagnostic Statements, Jan. through Dec. The Regional Director, Bureau of Meteorology, GPO Box 735, Darwin, Northern Territory 0801, Austalia.

Bartels, D.L., and R.A. Maddox, 1990: Midlevel cyclonic vortices generated by mesoscale convective systems. Mon. Wea. Rev., 119, pp 104. 118.

Bister, M., and K.A. Emanuel, 1995: On tropical cyclogenesis from mesoscale convective systems: a model study of a mechanism suggested by observations in TEXMEX. Preprints. 21st Conference on Hurricanes and Tropical Meteorology. American Meteorological Society, Boston, MA, 660 pp.

Brand, S., 1970: Interaction of binary tropical cyclones in the western North Pacific Ocean. *J. Appl. Meteor.*, 9, pp 433-441.

Brand, S., 1972: Very large and very small typhoons of the western North Pacific Ocean. *J. Meteor. Soc. Japan*, 50, pp 332-341.

Businger, S., and Baik, J-J., 1991: An arctic hurricane over the Bering Sea. *Mon. Wea. Rev.*, 119, pp 2293-2322.

Carr, L.E. , and R.L. Elsberry, 1994: Monsoonal interactions leading to sudden tropical cyclone track changes. *Mon. Wea. Rev.*, 123, pp 265-289.

Carr, L.E., and R.L. Elsberry, 1994: Systematic and integrated approach to tropical cyclone track forecasting, Part I: Description of basic approach. Naval Postgraduate School publication NPS-MR-002. Naval Postgraduate School, Monterey, CA 93943. 65 pp. plus figs. and append.

Carr, L.E., M.A. Boothe, S.R. White, C.S. Kent, and R.L. Elsberry, 1995: Systematic and integrated approach to tropical cyclone track forecasting. Part II: Climatology reproducibility, and refinement of meteorological knowledge base. Naval Postgraduate School publication NPS-MR-95-001. Naval Postgraduate School, Monterey, CA 93943, 96 pp.

Climate Analysis Center, 1994: Monthly 850-mb and 200-mb wind anomalies. *Climate Diagnostics Bulletin*. U.S. Prediction Center Dept of Commerce, Washington, D.C. month by bulletins.

Diercks, J. M., R. C. Weir and M. K. Kopper, 1982: Forecast verification and reconnaissance data for Southern Hemisphere tropical cyclones (July 1980 through June 1982). NOCC/JTWC Technical Note 82-1, 77 pp.

Dong, K. and C. J. Neumann, 1983: On the relative motion of binary tropical cyclones. *Mon. Wea. Rev.*, 111, pp 945-953.

Dunnavan, G. M., 1981: Forecasting intense tropical cyclones using 700-mb equivalent potential temperature and central sea-level pressure. NOCC/JTWC Technical Note 81-1, 12 pp.

Dvorak, V. F., 1975: TC intensity analysis and forecasting from satellite imagery. *Mon. Wea. Rev.*, 103, No. 5, pp 420-430.

Dvorak, V. F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Technical Report NESDIS 11, 46 pp.

Elsberry, R.L., W.M. Frank, G.J. Holland, J.D. Jarrell, and R.L. Southern, 1987: A global view of tropical cyclones. Limited edition publication sponsored by the U.S. Navy, Office of Naval Research, Washington DC, 185 pp.

Emanuel, K.A., 1992: The physics of tropical cyclogenesis in the eastern Pacific. Presentation at the International Symposium on Tropical Cyclone Disasters, Beijing, China, 12-16 October.

Frank, W.M., and S. Chen, 1991: Simulations of vortex formation in convective weather systems. Preprints, 19th Conference on Hurricanes and Tropical Meteorology. American Meteorological Society, Boston, MA.

Fujiwhara, S., 1921: The natural tendency towards symmetry, etc. Quart. J. Roy. Meteor. Soc., 47, pp 287-293.

Fujiwhara, S., 1923: On the growth and decay of vortical systems. Quart. J. Roy. Meteor. Soc., 49, pp 75-104.

Fujiwhara, S., 1931: Short note on the behavior of two vortices. Proc. Phys. Math. Soc. Japan, Ser. 3, 13, pp 106-110.

Glass, M., and G.W. Felde, 1990: Tropical storm structure analysis using SSM/I and OLS data. 5th Intl. Conf. on Interactive and Info. Processing Systems for Meteor., Oceanogr. and Hydrol., Aneheim, CA, Amer. Meteor. Soc., 432-437.

Gray, W.M., 1968: Global view of the origin of tropical disturbances and storms. Mon. Wea. Rev., 96, pp 669-700.

Guard, C.P., 1983: A Study of western North Pacific tropical storms and typhoons that intensify after recurvature. First Weather Wing Technical Note-83/002, 28 pp.

Harr, P.A., and R.L. Elsberry, 1991: Tropical cyclone track characteristics as a function of large-scale circulation anomalies. Mon. Wea. Rev., 119, pp 1448-1468.

Harr, P.A., and R.L. Elsberry, 1995: Large-scale circulation variability over the tropical western North Pacific. Part I: Spatial patterns and tropical cyclone characteristics. Mon. Wea. Rev. 123, pp 1225-1246.

Hawkins, H.F., and D.T. Rubsam, 1967: Hurricane Inez -- a classic "micro-hurricane". Mariners Weather Log, 11, pp 157-160.

Hebert, P.J., 1973: Subtropical cyclones. Mariners Weather Log, 4, pp 203-207.

Herbert, P. H. and K. O. Poteat, 1975: A satellite classification technique for subtropical cyclones. NOAA Technical Memorandum NWS SR-83, 25 pp.

Holland, G. J., 1980: An analytical model of wind and pressure profiles in hurricanes, 108, No. 8, pp 1212-1218.

Holland, G.J., 1987: [Tropical cyclone] mature structure and structure change. A Global View of Tropical Cyclones. R.L. Elsberry, Ed. [Limited edition publication sponsored by the U.S. Navy, Office of Naval Research].

Holliday, C. R. and A. H. Thompson, 1979: Climatological characteristics of rapidly intensifying typhoons. Mon. Wea. Rev., 107, No 8, pp 1022-1034.

JMA, 1976: The north-oriented track type. Forecasting Manual for Typhoons, [English version], Available in English or Japanese from the Japan Meteorological Agency, 1-3-4 Ote-machi, Chiyoda-ku, Tokyo, Japan, pp 194-197.

JTWC, 1993: Illustration of the cloud distribution in a monsoon depression. 1993 Annual Tropical Cyclone Report, JTWC, p 130.. [NTIS AD A285097].

Keen, R.A. 1982: The role of cross-equatorial tropical cyclone pairs in the Southern Oscillation. 110, pp 1405-1416.

Kepert, J.D., 1993: Research rapporteur report on oceanography and air-sea interaction. Annex to Topic Rapporteur Reports of the Third WMO/ICSU International Workshop on Tropical Cyclones (JTWC-III), Huatulco, Santa Cruz, Mexico, 22 November -1 December 1993. WMO/TD No. 573. Secretariat of the WMO, Geneva, Switzerland.

Krayer, W.R., and R.D. Marshall, 1992: Gust factors applied to hurricane winds. Bull. Amer. Meteor. Soc., 73, pp 613-617.

Kurihara, Y., 1992: Surface conditions in tropical cyclone models. In Modeling Severe Weather: Papers presented at the Fourth BMRC Modeling Workshop.Bureau of Meteorology Research Centre, Melbourne, Australia.

Lander, M. A., 1990: Evolution of the cloud pattern during the formation of tropical cyclone twins symmetrical with respect to the equator. Mon. Wea. Rev., 118, No. 5, pp 1194-1202.

Lander, M.A., and G.J. Holland, 1993: On the interaction of tropical-cyclone scale vortices. I: Observations. Quart. J. Roy. Meteor. Soc., 119, pp 1347 - 1361.

Lander, M.A., 1994a: Description of a monsoon gyre and its effects on the tropical cyclones in the western North Pacific during August 1991. *Weather and Forecasting*, 9, pp 640-654.

Lander, M.A., 1994b: An exploration of the relationships between tropical storm formation in the Western North Pacific and ENSO, *Mon. Wea. Rev.*, 122, No. 4, pp 636-651.

Lander, M.A., 1995a: Specific tropical cyclone track types and unusual tropical cyclone motions associated with a reverse-oriented monsoon trough in the western North Pacific. *Weather and Forecasting*, 11, No. 2. pp 170-186.

Lander, M.A., 1995b: The merger of two tropical cyclones. (Submitted to *Mon. Wea. Rev.*)

Lander, M.A., 1996: Specific tropical cyclone track types and unusual tropical cyclone motions associated with a reverse-oriented monsoon trough in the western North Pacific. *Weather and Forecasting*, 11, No. 2, pp 170-186.

Liu, W.T., K.B. Katsaros, and J.A. Businger, 1979: Bulk parameterizations of air-sea exchanges of heat and water vapor including the molecular constraints at the interface. *J. Atmos. Sci.*, 36, pp 1722-1735.

Luther, D.S., D.E. Harrison and R.A. Knox, 1983: Zonal winds in the Central Equatorial Pacific and El Niño.*Science*, 222, pp 327-330.

Matsumoto, C. R., 1984: A statistical method for one- to three-day tropical cyclone track prediction. Colorado State University Department of Atmospheric Science, Paper 379, 201 pp.

Mckinley, E.J., and R.L. Elsberry, 1993: Observations during TCM 92 of the role of tropical mesoscale convective systems in tropical cyclogenesis. Preprints, 20th Conference on Hurricanes and Tropical Meteorology. American Meteorological Society, Boston, MA. 623 pp. plus 64 joint pages.

Merrill, R.T., 1982: The comparison of large and small tropical cyclones. Colorado State University Department of Atmospheric Science, Paper 352, 75 pp.

Mundell, D.B., 1990: Prediction of tropical cyclone rapid intensification events. Thesis for fulfillment of Master's degree submitted to Colorado State University, 186 pp.

OFCM, 1993: National Hurricane Operations Plan, U.S. Dept. of Commerce, Washington, D.C., p E-1.

Price, J.F., 1981: Upper ocean response to a hurricane. J. Phys. Oceanogr., 11, 153-175.

Ramage, C.S., 1986: El Nino. *Scientific American*, May Issue, pp 77-84.

Ramage, C.S., 1971: Monsoon Meteorology. Academic Press, 296 pp.

Rupp, J.A., and M.A. Lander, 1996: A technique for estimating recurrence intervals of tropical cyclone-related high winds in the the tropics: results for Guam. *J. Appl. Meteorol.*, 35, pp 627-637.

Sadler, J.C., 1975: The upper circulation over the global tropics. UHMET Pub. 75-05. Dept. of Meteor., Univ. of Hawaii, Honolulu, HI 96822.

Sadler, J.C., 1967: The tropical upper tropospheric trough as a secondary source of typhoons and a primary source of trade wind disturbances. Final Report, contract No. AF 19(628)-3860, HIG Report 67-12, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, HI, 44 pp.

Sadler, J.C., 1976: A role of the tropical upper tropospheric trough in early season typhoon development. *Mon. Wea. Rev.*, 104, pp 1266-1278.

Sadler, J.C., M.A. Lander, A.M. Hori, and L.K. Oda, 1987: Tropical marine climatic Atlas, Vol II, Pacific Ocean. UHMET 87-02, University of Hawaii, Department of Meteorology, 14 pp.

Sadler, J.C., 1979: Tropical cyclone initiation of the tropical upper-tropospheric trough. Naval Environmental Prediction Research Facility Paper No. 2-76, 103 pp.

Sandgathe, S. A., 1987: Opportunities for tropical cyclone motion research in the Northwest Pacific region. Technical Report NPS 63-87-006, Naval Postgraduate School, Monterey, CA 93943, 36 pp.

Shoemaker, D.N., 1991: Characteristics of tropical cyclones affecting the Philippine Islands. NOCC/JTWC Technical Note 91-01, 35 pp.

Simpson, R.H., 1974: The hurricane disaster potential scale. *Weatherwise*, 27, pp 169-186.

Spratt, S.M., 1990: Tropical cyclone cloud patterns: climatology and relationships to intensity changes. Master's Thesis. Department of Meteorology, University of Hawaii, 2525 Correa Rd., Honolulu, HI 96822.

Weatherford, C.L. and W.M. Gray, 1985: Typhoon Structural Variability. Colorado State University Department of Atmospheric Science, Paper No. 391, 77 pp.

Weir, R. C., 1982: Predicting the acceleration of northward-moving tropical cyclones using upper-tropospheric winds. NOCC/JTWC Technical Note 82-2, 40 pp.

Willoughby, H.E., J.A. Clos, and M.G., 1982: Concentric eye walls, secondary wind maxima, and the evolution of the hurricane vortex. *J. Atmos. Sci.*, **39**, pp 395-411.

Willoughby, H.E., 1990: Temporal changes in the primary circulation in tropical cyclones. *J. Atmos. Sci.*, **47**, pp 242-264.

Wirfel, W. P. and S. A. Sandgathe, 1986: Forecast verification and reconnaissance data for Southern Hemisphere tropical cyclones (July 1982 through June 1984). NOCC/JTWC Technical Note 86-1, 102 pp.

Xu, Y. and C. J. Neumann, 1985: A statistical model for the prediction of western North Pacific tropical cyclone motion. NOAA Technical Memorandum NWS NHC 28, 30 pp.

Zehr, R.M., 1992: Tropical cyclogenesis in the western North Pacific. NOAA Technical Report, NESDIS 61, U.S. Dept. of Commerce, Washington DC, 181 pp.